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# IGY BULLETIN

*A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs.*

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## Cosmic Rays from Solar Flares

*The following report is based on a paper presented by J. R. Winckler, of the University of Minnesota Department of Physics, at the Symposium on Upper Atmosphere Solar Relations, held during the December 28, 1959, meeting of the American Association for the Advancement of Science, Chicago, Illinois.*

In considering the nature and source of primary cosmic rays, the question frequently arises as to whether the sun, as a typical star, is a source of cosmic radiation. It is known that the sun sporadically emits bursts of high-energy cosmic rays, since five such bursts were detected by sea-level monitoring instruments during the past 15 years. The most recent was observed as a great increase in cosmic-ray intensity on February 23, 1956. On the basis of these five events, it was widely believed prior to the IGY that the sun seems to emit either large bursts of cosmic rays or none at all.

During the IGY and IGC-59 period, however, improved techniques for studying cosmic rays at high altitudes have resulted in approximately 25 additional observations of intense cosmic-ray emission from the sun. Though similar in nature to the cosmic rays detected in the five sea-level cases, those observed at high altitudes have lower average energies and therefore do not penetrate deep enough into the atmosphere to be detectible by the world-wide network of sea-level monitors. These observations of solar cosmic rays at high altitudes have added greatly to an understanding of the process by which solar cosmic rays are accelerated, of their propagation through space, and of their interactions with the earth's magnetic field and upper atmosphere. (See *Bulletins 3, 4, 8, 10, 11, 15, 25,* and *31* for additional information on the IGY and IGC-59 cosmic-ray programs and results. *Bulletin No. 25* contains a relatively detailed report on one of the high-altitude solar-cosmic-ray events not described in the present report.)

Observations of these high-altitude

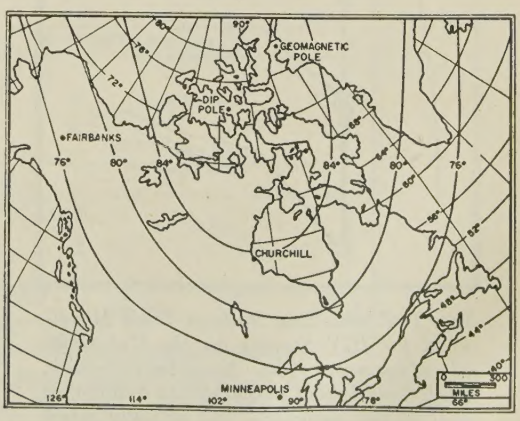


Fig. 1. *Locations of Balloon Launching Sites Relative to Geomagnetic Latitude.*

events during the IGY and IGC-59 fall into three categories: i) direct measurements of cosmic-ray particles with balloon-borne equipment (Figs. 1 and 2); ii) direct measurements with satellites; and iii) measurements of increases in ionospheric electron density over the earth's "polar cap," caused by collisions of cosmic rays with atmospheric particles. This report is concerned primarily with results of the balloon observations, but associated ionospheric effects and satellite measurements are also mentioned where appropriate. All 25 events were detected by means of their ionospheric effects, 11 were also observed by balloon flights, and four also by satellites.

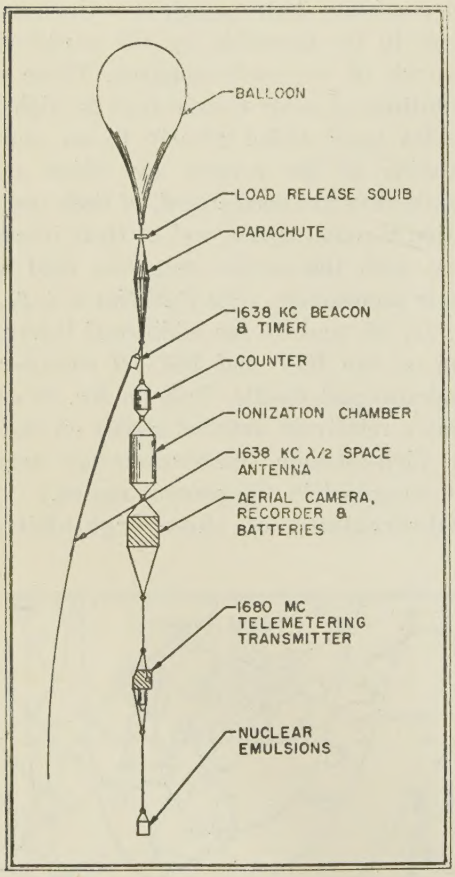


Fig. 2. *Cosmic-Ray Balloon Train Developed for IGY Studies by the University of Minnesota. The ¾-millimeter-thick, 180,000-cubic-foot polyethylene balloon, as well as the parachute, are actually much larger than shown relative to the instrumentation.*

## The Balloon Program

The over-all IGY and IGC-59 balloon program of cosmic-ray measurements at high altitudes included approximately 100 flights conducted by the University of Minnesota, 20 to 25 flights by the University of Iowa, and a considerable number by University of Chicago and University of California groups. The flights were made at several different latitudes: launching sites included Fairbanks, Alaska; Fort Churchill, Canada; Minneapolis; Chicago; and other locations.

A standard balloon "train" (see Fig. 2) was developed for the IGY program by the University of Minnesota. University of Iowa balloon experiments were similar in many respects. Instruments in the University of Minnesota train consist basically of an integrating ionization chamber, a single Geiger counter, and a package of nuclear emulsions. The ionization chamber and Geiger counter are essentially omni-directional in response, and both give a continuous recording of the radiation intensity. By comparing their readings it is frequently possible to evaluate the mean ionization and the energies of the particles and to obtain information about their nature and variations with time. The nuclear emulsions permit evaluation of the types of particles and the energy spectrum.

## Solar-Cosmic-Ray Outbursts

In order to examine the characteristics of these solar-cosmic-ray events, three particularly good examples have been selected. All three events were detected both by their ionospheric effects and by balloon measurements, and one was also detected by a US-IGY satellite.

*Event of August 22, 1958:* This solar cosmic-ray event was especially well ob-

served by balloons, satellites, and ionospheric detectors. Figure 1 shows the locations of the balloon observations with respect to the high geomagnetic and geographic latitudes over North America. Balloon experiments were conducted during the event at Fort Churchill, Canada, by K. A. Anderson of the University of Iowa; at Fairbanks, Alaska, by a University of Minnesota group in cooperation with the University of Alaska; and at Minneapolis, also by the University of Minnesota.

Figure 3 summarizes the principal flight results from Fort Churchill, Fairbanks, and Minneapolis, and from the sea-level neutron monitor at Deep River, Ontario, Canada. The Fort Churchill balloon, launched at about 1200 UT, August 22, was floating at high altitude at the time of occurrence of a Class 3+ flare in the sun's chromosphere, about two hours later. (Class 3+ is the highest category in the flare-importance classification system, based on solar-disk area covered by flares.) Within an hour, the balloon's instruments showed large counting-rate increases, which reached a peak about 20 times the normal cosmic-ray intensity. The great burst of cosmic rays decreased after about four hours and then declined smoothly, but two days later the radiation intensity observed was still slightly higher than the normal cosmic-ray background intensity. It appears from the flight data that particle incidence in these events is very irregular during the first four hours, with minima and maxima occurring in a random manner, followed by a smooth fading away.

A flight was also in the air at Minneapolis at the time of the flare, but it observed no similar effects. This clearly shows that the phenomenon resulted from the arrival

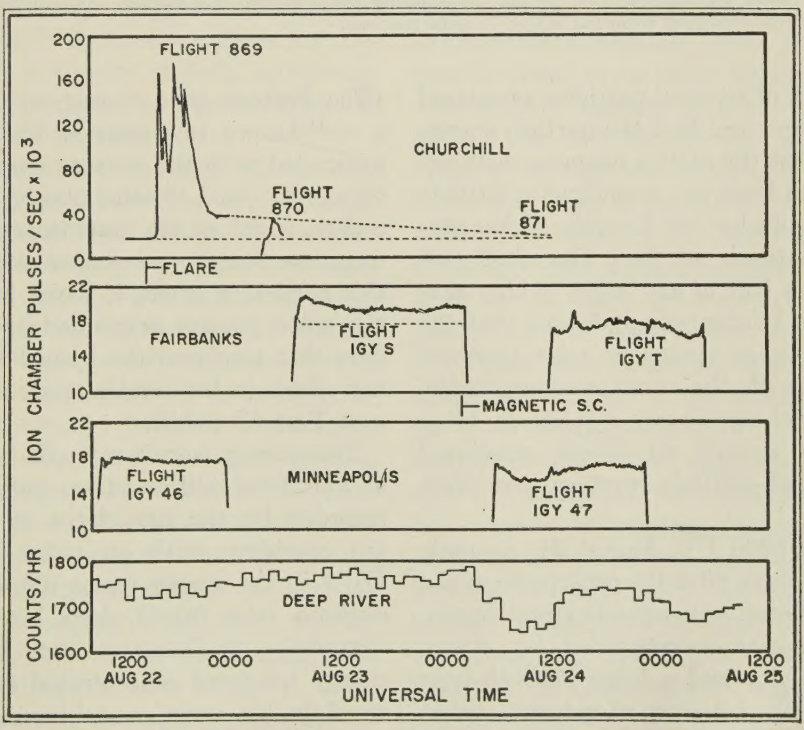


**Fig. 3.** *Summary of Principal Flight Results from Fort Churchill, Fairbanks, and Minneapolis, and Data from the Sea-Level Neutron Monitor at Deep River, Canada, for the August 1958 Event. (Deep River data courtesy of Hugh Carmichael.) Dashed horizontal lines represent approximate level of normal background cosmic-ray intensity.*

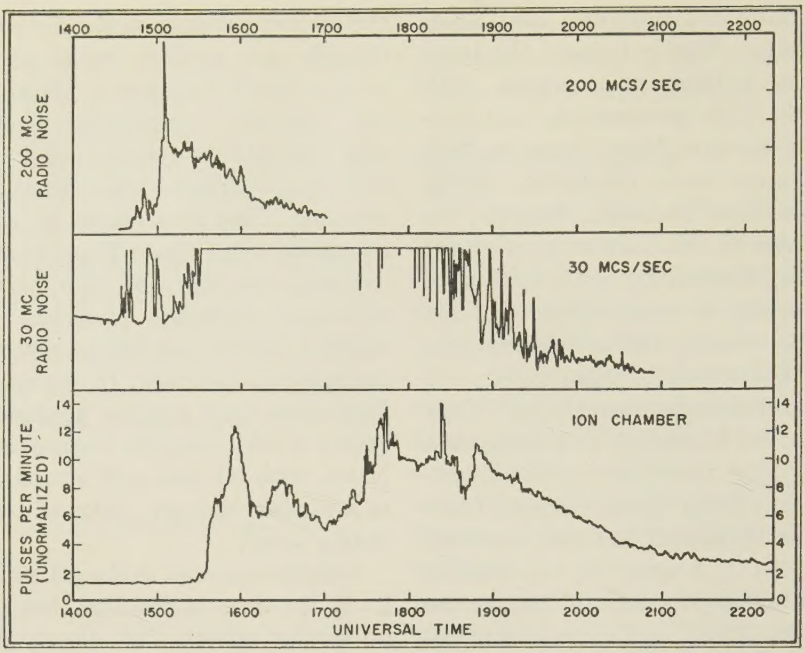


Fig. 4. *Comparison of Ion Chamber Data at High Altitude with Solar Radio Noise Data for the August 1958 Event. The 30-megacycle profile shows sequence from normal cosmic-noise level to noise bursts, followed by the long-lasting noise storm, and finally, the attenuation of cosmic noise resulting from the influx of solar protons.*

at the earth of charged particles associated with the flare, and that the particle energy was such that the earth's magnetic field excluded them from the geomagnetic latitude of Minneapolis but not from the higher geomagnetic latitude of Fort Churchill (see Fig. 2). This lack of any effect at high altitude above Minneapolis indicates that the number of solar $\gamma$-rays or solar neutrons associated with the event was negligible. The sea-level cosmic-ray monitor at Deep River also showed no effects associated with the high-altitude increase over Fort Churchill.

At about 0330 UT, August 24, approximately 1½ days after the occurrence of the flare, an intense geomagnetic storm began. The storm was accompanied by strong auroral activity and a large Forbush-type decrease in the intensity of galactic cosmic rays, as shown by the sea-level monitor and by balloon flights at Fairbanks and Minneapolis (see Fig. 3, IGY T and IGY 47). (The Forbush-type cosmic-ray decrease is a well-known phenomenon thought to be associated with the passage over the earth of a great cloud of solar plasma ejected by a flare, which at the same time generates a magnetic storm and causes auroras.) In this particular event, it seems certain that the solar plasma originated in the same flare that produced the immediate cosmic-ray effects in the earth's upper atmosphere over Fort Churchill.

The strong cosmic-ray effects observed at Fort Churchill and the smaller increase recorded by the first flight at Fairbanks are consistent with an influx of protons ($H^+$) in the energy range 100–400 million electron volts (mev). Also, both the Fort Churchill and Fairbanks data indicate an energy spectrum concentrated strongly toward the low energies and having very few high-energy particles. Although the lower energy limit detectible by the balloon instrumentation was 100 mev, measurements

by IGY satellite 1958 Epsilon (Explorer IV), which was making continuous passes over the northern United States at the time of the event, extend the lower limit downward to energies as low as 30 mev.

An important correlation was also made between the cosmic rays observed at the earth following the August 22 flare and the intense solar-radio-noise bursts observed during the flare (see Fig. 4). The radio emission from this flare was of the continuum-outburst type, or Type IV in the spectral classification system for solar radio emission (see *Bulletin No. 29*). It is believed that this type of solar radio spectrum is emitted by synchrotron-type radiation produced in a flare region. It seems probable that the acceleration of high-energy particles on the sun is closely associated with these same magnetic regions and that there is essentially a 1–to–1 correlation between the cosmic-ray particles and the Type IV radio emission from a particular flare. As shown in Figure 4, moreover, there is a suggestion of a similarity of form in the cosmic-ray and radio-noise records from the flare of August 22, 1958.

The observation of particles at high altitudes more than a day after the flare indicates that, in addition to an acceleration mechanism, a storage mechanism is also necessary to explain the continuing influx of particles throughout this period. (In the still more intense events discussed below, particles were observed for as long as 11 days after the flare.) Of the several storage mechanisms suggested, the experimental facts are best fitted by storage in the vicinity of the sun and the assumption that the stored particles escape from the storage region, by diffusion or an equivalent mechanism, until the supply is exhausted and the intensity observed at the earth again falls to the normal background value.

The decrease in galactic cosmic rays at the time of the geomagnetic storm has previously been explained by other investigators in terms of a mechanism in which

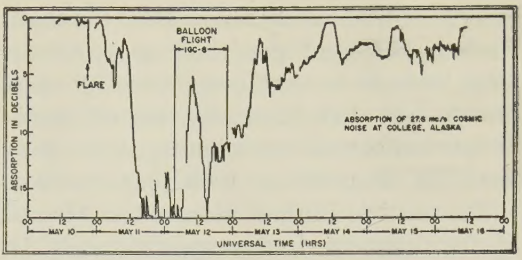


Fig. 5. *Absorption of Galactic Radio Noise During the May 1959 Event, Indicating Bombardment of the Polar Cap by Solar Cosmic Rays. (Courtesy of Leinbach and Reid.) Flight IGC–8 was conducted by the University of Minnesota group at Minneapolis.*

the galactic particles are diverted away from the earth by magnetic fields associated with the plasma cloud blown out from the flare. However, since the solar cosmic rays begin to reach the earth almost immediately following the flare, whereas the cloud arrives a day or two later, it is evident that the particles cannot be trapped in these same magnetic fields. Possibly the plasma cloud is actually highly turbulent and contains isolated magnetic fields, permitting the solar cosmic rays to penetrate directly through the cloud and reach the earth with only a time-of-flight delay.

*Event of May 11–12, 1959:* This event also began with a Class 3+ flare—at about 2000 UT on May 10—and extremely intense Type IV solar radio noise. Within four hours after the beginning of the visible flare, the D-layer of the ionosphere over the polar cap began to show an increase of radio-wave absorption, indicating the presence of cosmic-ray particles. The absorption reached its maximum intensity about 12 hours after the flare and was still detectible five days later (see Fig. 5). Following notification of the onset of the polar-cap absorption, by H. Leinbach and G. C. Reid of the University of Alaska's Geophysical Institute, the University of Minnesota group conducted a series of balloon flights at Minneapolis; the series began after the sudden commencement of the geomag-

netic storm, about 26 hours after the flare. Records of these flights show an extremely large increase in cosmic-ray intensity—approximately 150 times the normal omnidirectional cosmic-ray intensity, and a vertical flux as much as 1000 times normal.

The particle increase observed at Minneapolis disappeared after approximately 12 hours, during which there were many fluctuations and a close association with the geomagnetic storm at that latitude. Although the event appears to differ from that of August 22, 1958, in this respect, the University of Minnesota investigators believe it to be actually of the same character. They believe that the unusual presence of particles during the geomagnetic storm was associated with the very high intensity of the event combined with a severe perturbation of the earth's magnetic field, permitting particles to enter at normally forbidden latitudes. (High-energy cosmic rays can penetrate the geomagnetic field at all latitudes; lower-energy particles are diverted by the magnetic field and can penetrate only at higher geomagnetic latitudes, the latitude "cutoffs" for different particles depending on their energies.)

The polar-cap ionosphere records indicate a continuous and long-lasting bombardment by these particles at high latitudes before, during, and after the transitory increase observed at Minneapolis in correlation with the geomagnetic storm. As usual in these events, a Forbush decrease in the sea-level intensity of galactic cosmic rays was observed. Hence, it is clear that in this event, also, the solar cosmic rays could not have been trapped in the plasma cloud from the flare, but came directly from the flare with a transit time of 4–12 hours and continued to impinge on the earth during the Forbush decrease.

An analysis of the nuclear emulsions carried in this series of flights, the first to provide good exposures of solar cosmic rays, was made by E. P. Ney and P. S. Freier of the University of Minnesota. The analysis shows that the particle spectrum, like that in the May 1958 event, was very steep and that the particles consisted almost entirely of protons. Detailed studies by Ney and Freier of emulsions from other flights have also shown the presence of electrons and alpha-particles at certain times during these strong geophysical events. Although in much smaller numbers than the protons, these electrons and alpha particles occur in excess of their numbers in the normal cosmic-ray flux.

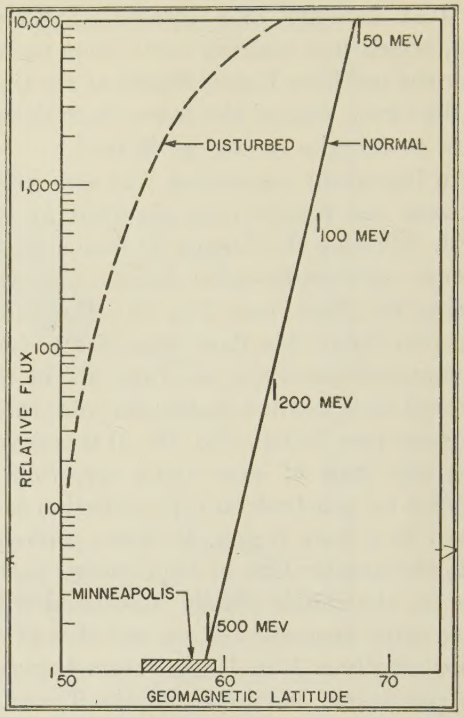


Fig. 6. *Estimate of Latitude Effect in the Vicinity of Minneapolis.*

It has previously been found that, in strong auroras at latitudes below the auroral zone (the high-latitude band along which auroras are most intense and most frequent), there is a close correlation between the presence of auroral X-rays and visual luminosity. Scintillator records for the Minneapolis flights during the May 1959 event show high counting rates at the time of maximum auroral activity accompanying the geomagnetic storm. The count-

ing rate reached its highest peak, 8000 counts/sec, at about 0830 UT on May 12. At exactly this time, the visual aurora was intense at the zenith over Minneapolis. In addition, detailed study of all-sky camera records from the stations at Choteau, Montana, Fargo, North Dakota, and Williams Bay, Wisconsin, shows that the aurora reached the zenith at the latitude of Minneapolis within a few minutes' time during the intense bursts of auroral X-rays.

The University of Minnesota investigators assume that the presence of low-energy solar cosmic rays at Minneapolis during the geomagnetic storm is evidence for a complete change of the Störmer cutoffs (the latitude cutoffs) of the earth's dipole magnetic field. Figure 6 shows graphically an estimate of this effect, which permits the entry of low-energy particles at lower-than-normal geomagnetic latitudes. Although the effect is not understood in detail, the University of Minnesota workers suggest a simple mechanism that may account for it: in the far reaches of the earth's magnetic field, the lines of force may break off and connect directly with a portion of the solar magnetic field carried outward by the plasma from the flare.

The May 1959 event was also observed by counters carried in Soviet meterological balloons at geomagnetic latitude 64° N. The shape of the spectrum deduced from their measurements is very similar to that obtained by the variety of instruments used at Minneapolis, and also closely resembles the spectrum of the August 1958 event.

*Series of events of July 1959:* In July 1959 a series of three great cosmic-ray flares occurred. The first began with a strong flare early on July 10, the second with a flare on July 14, and third followed a flare on July 16 (see Fig. 7). The three outbursts, covering virtually the entire period from July 10 to 18, were all presumably caused by solar protons having very steep energy spectra, as were the first two

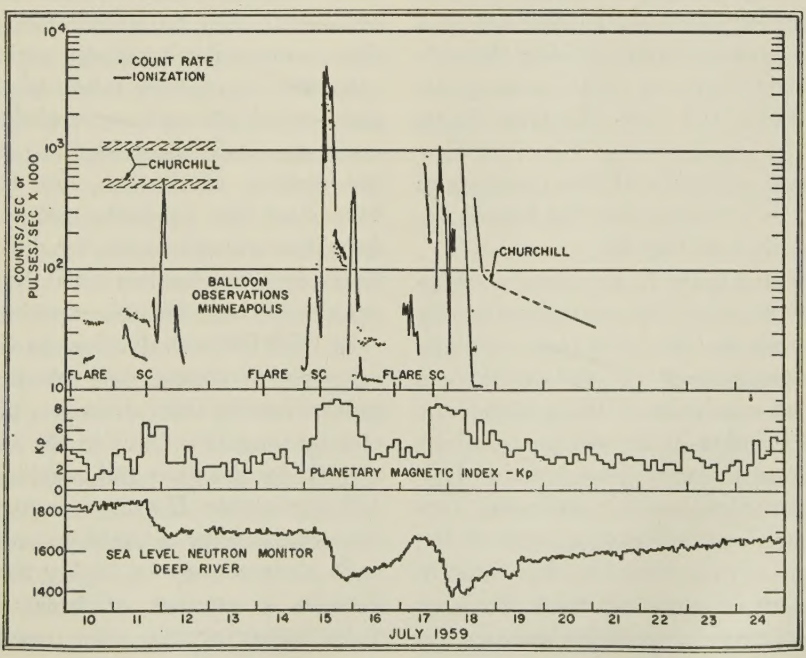


Fig. 7. *Correlation of Minneapolis and Fort Churchill Balloon Data with Planetary Magnetic Indices and Sea-Level Neutron-Monitor Data for the Three Events of July 1959.*

events described, and were therefore not detectible by sea-level instruments.

In all cases, the high-altitude observations over Minneapolis showed a strong correlation with geomagnetic activity, a condition that seems necessary to permit the normally forbidden lower-energy particles to penetrate to balloon altitudes at that geomagnetic latitude. Polar-cap ionospheric effects appear to have been intense and continuous throughout the period. Balloon flights conducted at Fort Churchill by James Earl, of the University of Minnesota, made direct observations, with nuclear emulsions and instruments, of the solar protons at high latitude during these events.

Although the first of the three July 1959 events ended at Minneapolis on July 12, two days after onset, it persisted at higher geomagnetic latitudes for many days, overlapping the flare of the 14th. This second cosmic-ray flare of the July 1959 series resulted in the highest intensity of solar cosmic rays observed by the University of Minnesota group. They estimate that an intensity possibly 10,000 times that of the normal background intensity may have been reached in space immediately after the sudden commencement of the geomagnetic storm following the flare. Balloon flights conducted by Anderson at Resolute Bay showed direct evidence of the presence of solar particles 11 days after the last of the three flares, that of July 16.

As shown in Figure 7, a striking correlation existed between the particle intensity at Minneapolis and the planetary magnetic indices, showing again the relation between the disturbed condition of the geomagnetic field and the influx of low-energy particles at lower-than-normal geomagnetic latitudes. Also shown are the enormous Forbush decreases accompanying each of the geomagnetic storms. Thus, in this series of events also, it is apparent that the large increases in lower-energy solar cosmic-rays at high altitude must arise from a different mechanism than that causing the decreases in high-energy galactic cosmic rays at sea level.

## Conclusions

Prior to the IGY, very-high-energy galactic cosmic rays and occasional bursts of high-energy solar cosmic rays, were detected by sea-level monitoring instruments. IGY and IGC-59 balloon studies have since shown that intense bursts of lower-energy cosmic rays, detectible only at high altitudes where they are subjected to less screening by the atmosphere, are also frequently associated with great solar flares. Analysis of three such events observed during the IGY and IGC-59, by balloons, satellites, and ionospheric-absorption recorders, permits the following conclusions and speculations:

1) A close correlation exists between the Type IV (continuum outburst) solar radio noise emitted by synchrotron-type radiation produced in flare regions and the cosmic-ray particles from the same flare region. Hence, it is likely that the particles are accelerated to cosmic-ray energies in these same solar magnetic regions.

2) The continuing influx of these particles for periods up to several days requires a storage mechanism; such a mechanism in the vicinity of the sun, and the assumption that the particles escape gradually from the storage region by diffusion or an equivalent mechanism until the supply is exhausted, best fits the experimental data.

3) The Forbush decrease in the sea-level intensity of cosmic rays coming from the galaxy results from diversion of the particles by magnetic fields in the solar plasma ejected by the flare and reaching the earth 1–2 days later. However, instead of being characterized by a uniform magnetic field, such a cloud may be highly turbulent and contain a number of isolated magnetic fields, allowing the solar cosmic rays to move directly through the cloud and reach the earth with only a time-of-flight delay.

Thus, the intensity of the lower-energy solar cosmic rays may remain high, or even increase, when the plasma cloud reaches the earth, while the intensity of the high-energy galactic cosmic rays falls off greatly.

4) Perturbation of the earth's magnetic field by the solar plasma cloud following a flare permits low-energy particles to penetrate the magnetic field at lower geomagnetic latitudes than normal. A simple mechanism suggested to explain this phenomenon is that the lines of force of the earth's magnetic field may break off in the far reaches of the field and connect with portions of the solar magnetic field carried in the plasma cloud.

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# United States Meteorological Satellite

At 6:40 am, April 1, 1960, the United States launched from Cape Canaveral, Florida, the Tiros I meteorological satellite. It entered a nearly circular orbit about 12 minutes later. The satellite, designated 1960 Beta 2, carries two small television cameras to take still photographs of the earth's cloud cover for transmission to receiving stations and subsequent use in meteorological research and analysis.

In accordance with customary procedures, orbital and instrumental details were sent immediately to the Committee on Space Research (COSPAR), in The Hague, for transmission to all COSPAR participants. Data acquired by the satellite will be deposited in the World Data Centers established during the IGY, and will also be forwarded to COSPAR. Thus, the data will be made available to the world scientific community.

Over-all responsibility for the Tiros project rests with the National Aeronautics and Space Administration. NASA's Goddard Space Flight Center, which directs the project, prepares the command programming relayed by the ground stations to the satellite. The programs are based on information from the NASA Computing Center and the Meteorological Satellite Section of the US Weather Bureau. Many other private and public agencies participated in the numerous phases of preparation of the satellite instrumentation, command and tracking facilities, and launching.

## Satellite Characteristics

1960 Beta 2 is shaped roughly like a large hatbox (see Fig. 8), 42 inches in diameter and 19 inches high. The satellite weighs 270 pounds and its top and sides are covered almost completely with banks of solar cells —some 9200 in all—which supply power for the experimental equipment. A single command receiving antenna extends perpendicularly outward from the top of the satellite, and four two-frequency transmitting antennas, 90° apart, extend diagonally outward from the bottom.

Wound around the outside of the satellite was a de-spin mechanism consisting of two weights attached to cables. About 10 minutes after payload separation from the third-stage rocket the weights unwound, slowing the satellite from its initial spin rate of about 136 revolutions per minute to 10 rpm, a rate at which unblurred pictures can be taken. Since interaction of the satellite's metal components with the earth's magnetic field tends to slow the spin further, two pairs of tiny rockets are located around the base plate to "spin up" the satellite again, on command, when the rate falls to 9 rpm, the minimum rate desired.

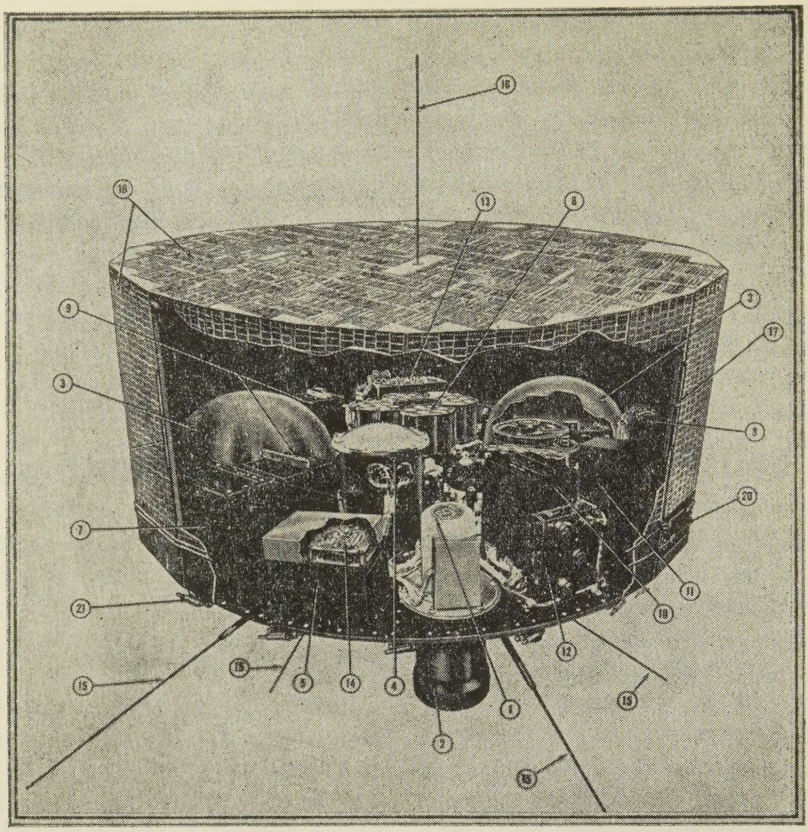


Fig. 8. *Cutaway View of 1960 Beta 2 (Tiros I). Key: 1) Vidicon television camera; 2) wide-angle lens; 3) tape recorder; 4) electronic timer for programming; 5) television transmitter; 6) chemical batteries; 7) camera electronics; 8) tape-recorder electronics; 9) control circuits; 10) auxiliary controls; 11) power converter for tape motor; 12) voltage regulator; 13) battery charging regulator; 14) auxiliary synchronizing generator for television camera; 15) transmitting antennas; 16) receiving antenna; 17) solar sensor; 18) solar cells; 20) de-spin mechanism; 21) spin-up rockets.*

## Launching Vehicle

1960 Beta 2 was boosted into orbit by a three-stage Thor-Able rocket similar to those used to launch satellite 1959 Delta (Explorer VI) and space probes Pioneer I and 1960 Alpha (Pioneer V). (*Bulletin No. 18* describes briefly the vehicle used to launch Pioneer I.) The Air Force Ballistic Missile Division had primary responsibility for development of the launching vehicle, for mating booster and payload, and for the launch.

The 1960 Beta 2 launching vehicle differed from previous Thor-Able vehicles in two respects: (1) For the first time in any NASA satellite launch, a tracking beacon was carried in the third-stage rocket, which remains in orbit with the probe. The third-stage rocket has been designated 1959 Beta 1. (2) Before its ignition, the third-stage was allowed to coast for about 6½ minutes after separation from the second stage. During this interval, the third stage and the payload were spin stabilized.

## Orbital Characteristics

At present, 1960 Beta 2 is approximately 433 statute miles above the earth's surface

at perigee and 465 miles high at apogee. Since a circular orbit at a distance of about 460 statute miles was intended, the orbit achieved, with an eccentricity (or deviation from a true circle) of only .003, is considered nearly perfect. The orbit is inclined at an angle of 48° to the equator, and the satellite's orbital period is approximately 99 minutes (see Fig. 9).

Burn-out velocity of the third stage was 16,812 miles per hour, slightly higher than the intended velocity. Because of its highly stable circular orbit, 1960 Beta 2 is expected to have a lifetime of some tens of years. Based on the estimated lifetime of the electronic equipment, however, the experiments are expected to cease functioning about three months from the date of launch.

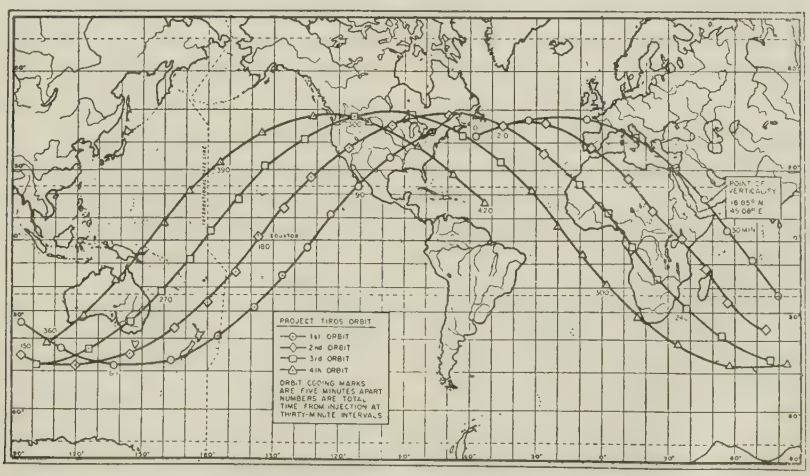
## Experiment and Instrumentation

The Tiros instrumentation and the special ground-station equipment required for the experiment were designed and constructed by the Astro-Electronic Products Division of RCA, under technical direction of the Goddard Space Flight Center and supervision of the US Army Signal Research and Development Laboratory. The Meteorological Satellite Section of the US Weather Bureau, assisted by military and private agencies, has primary responsibility for analysis and interpretation of the cloud-cover data gathered by the satellite.

An ultimate goal of the weather forecaster is to have synoptic world-wide meteorological observations available at all times. Present observing networks cover about one-fifth of the total atmospheric mass, leaving large oceanic areas, desert and polar regions, and other remote portions of the globe completely devoid of weather observing stations. Storms may reside in such areas for days without detection.

Pictures such as those obtained by 1960 Beta 2 show cloud patterns indicating the birth, or subsequent stages of development, of hurricanes, cyclones, and other kinds of weather activity in areas far from normal observation stations. Ultimately, such photographs, plus other meteorological information obtainable only by satellites, may greatly improve our understanding of the causes and patterns of weather and our ability to forecast. Perhaps some theories relating to weather control may also result.

The major instrumentation in 1960 Beta 2 consists of two television cameras approximately the size of a water glass. Except for lens equipment, the cameras are identical, consisting essentially of a ½-inch Vidi-


PROJECT TIROS ORBIT
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ORBIT CODING MARKS ARE FIVE MINUTES APART NUMBERS ARE TOTAL TIME FROM INJECTION AT THIRTY-MINUTE INTERVALS
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Fig. 9. *Earth Trace of First Four Orbits of 1960 Beta 2.*

con tube and a focal-plane shutter that permits storage of still pictures on the tube screen. An electron beam converts the stored pictures into television-type electronic signals, which are transmitted to ground receivers on command.

One camera has a wide-angle, f/1.5 lens of relatively low resolution; this camera is capable of covering an area of the earth's surface (from an altitude of about 460 statute miles) roughly 700 to 800 miles square. The pictures overlap, thus providing continuous coverage during the operating periods of the cameras. The second camera, which has a narrow-angle, relatively high-resolution, f/1.8 lens, covers an area approximately 80 miles on a side in about the center of that covered by the wide-angle camera. The wide-angle camera, with a resolution of about 1½ miles, is designed to provide pictures of broad cloud-cover patterns (see Fig. 10), while the narrow-angle camera, with a resolution of a little more than 1/10 mile, shows specific cloud types in greater detail. Both cameras have shutter speeds of 1.5 milliseconds and video bandwidths of 62.5 kilocycles; both take 1/2 frame per second, and each frame has 500 lines.

Magnetic tape recorders connected to each camera can store up to 32 photographs each for later relay on command from a ground station. Also, if desired, new picture data from the cameras can by-pass the tape containing stored data and be transmitted directly when so commanded by a nearby station. The tapes are automatically erased with each "read-out," and then re-wound immediately for the next recording. Each television system includes a two-watt transmitter sending at a frequency of 235.00 megacycles per second. The two systems and their associated equipment are completely independent of one another.

Photographic data are transmitted from one camera at a time, and tape read-out from both cameras takes 3½ minutes. The satellite is within transmission range of a ground station for as much as 12 minutes, and can send up to four minutes of photographic data collected while within range of the station. Immediately after being received at a ground station, the pictures are displayed on kinescopes for viewing and photographing. All original data are stored at NASA's Goddard Space Flight Center.

In order to identify the photographs geographically, the satellite's orbit is accurately computed by tracking reports. In addition, nine solar sensors on the satellite provide directional orientation by measuring the position of the satellite with respect to the sun. This information is transmitted to the ground station along with the photographic data; processing by computer then shows the north direction for each picture. An infra-red detector within the payload senses the crossing of the earth's horizon by the detector's line of sight, making it possible, in principal, to determine the attitude in space of the satellite's spin axis. However, the operation of this circuit has been erratic, and attitude data are slowly being obtained by photogrammetric analysis of known landmarks visible in the pictures.

Since 1960 Beta 2 is spinning on its axis, it cannot "look" at the earth at all times. Moreover, pictures cannot be taken when the satellite is over the night side of the earth, and Southern Hemisphere data cannot readily be correlated with ground-based meteorological observations. Hence, the cameras are programmed to take photographs only when the satellite is viewing the sunlit portion of the earth's Northern Hemisphere. Program commands can be given as much as five hours in advance.

## Command Stations

All control and programming functions are prepared at the Tiros Technical Center of Goddard Space Flight Center. The programs prepared are sent to the data-acquisition stations for relay to the satellite. These

Fig. 10. *1960 Beta 2 Photograph of Storm Centered Over Nebraska on April 1, 1960, and Appropriate Surface Weather Map of Same Area. Circular cloud mass in upper part of picture is storm center; prominent cold front trails south and southwest from storm; large cloud mass in foreground was located near Gulf Coast. Photograph taken on satellite's fifth orbit, from height of about 450 miles over geographic position marked by "X".*

stations are under the direction of Goddard Space Flight Center.

There are two primary ground stations in the Tiros experiment. One, at Fort Monmouth, New Jersey, is operated by the US Army Signal Corps; the other, at Kaena Point, Hawaii, is operated by the Lockheed Missile and Space Division under contract to AFBMD and under technical supervision of the Signal Corps. Both stations can command the satellite and receive photographic data. Two "back-up" stations, which cannot command the satellite but which can receive data, are at Cape Canaveral, Florida, and Princeton, New Jersey.

The Fort Monmouth station programmed the television cameras of 1960 Beta 2 for the first time on April 1, 1960, about 1½ hours after launch, when the satellite made its first sweep over the East Coast of the United States. Since then, 1960 Beta 2 has been interrogated many times by both stations, producing a large number of unexpectedly useful photographs showing cloud patterns and broad geographic features on the earth's surface (Fig. 10).

## Tracking

1960 Beta 2 carries two beacon transmitters for tracking purposes. The transmitters, operating on frequencies of 108.00 megacycles and 108.03 megacycles, both have a power output of 30 milliwatts. The signals of both transmitters can be modulated to provide information on satellite attitude, environmental conditions, and operation of the equipment carried by the satellite. To insure against failure of the entire experiment in case of damage to, or failure of, one of the transmitters, both frequencies carry the same data.

As mentioned previously, 1960 Beta 1, the third-stage rocket casing in orbit with the satellite, also carries a beacon transmitter for tracking purposes. This transmitter was battery-powered and lasted one day.

Operational tracking is provided by the NASA Minitrack network, originally established for the IGY Satellite Program. Each of the stations set up to acquire photographic data is also equipped with tracking antennas.

### Preliminary Results

After about three weeks in orbit, 1960 Beta 2 had circled the globe about 300 times and taken about 6000 cloud-cover photographs. Weather Bureau meteorologists were able to compare the photographs with weather patterns observed by standard techniques and to arrive at certain preliminary conclusions. The satellite pictures reveal an unexpectedly large degree of organization in the cloud systems over much of the earth.

The most striking patterns found in the photographs are banded, inward-spiralling cloud formations associated with large storms, some as much as 1500 miles across, observed over the United States as well as over the North Atlantic, North and South Pacific, and Indian Oceans. It was previously known from radar observations that such spiral patterns characterize large tropical storms—hurricanes, typhoons, and milder disturbances. The 1960 Beta 2 observations show that such structure also exists around well-developed storms outside the tropics.

Thus far, the storms observed over continents have not exhibited as strongly pronounced banded structure as oceanic storms. In storms over the oceans, cloud bands are a few miles to a few hundred miles wide and are separated by clear zones. Over the continents, cloud areas are more general, with only poorly defined spaces between bands, or none at all. The spiral nature of the continental storms is indicated, however, by a characteristic wedge of cloudless air curving in toward the storm center behind a cold front, as shown in the Midwest storm of April 1 (Fig. 10).

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# Explosive Warming in the Antarctic Stratosphere

*The following material is based on a paper given by Kirby J. Hanson, US Weather Bureau, at the Symposium on Antarctic Meteorology, Melbourne, Australia, February 1959. Mr. Hanson was Chief Meteorologist at the IGY Amundsen-Scott South Pole Station during the 1957–58 period.*

With the establishment of IGY Amundsen-Scott South Pole Station, meteorologists were able to gain an insight into the annual temperature variations over the extremely cold south-polar snowfield and into the relationship of these variations to global temperature structure and atmospheric processes. This report describes one of many temperature processes from which evolves the annual stratospheric temperature pattern over the geographic South Pole.

### Monthly Mean Stratospheric Temperature

The past few years' data reveal the properties of the annual variation of monthly mean stratospheric temperature with height over the geographic South Pole. These data show that, at a height of 19 kilometers (50-millibar constant-pressure level), the stratosphere cools for eight continuous months, ranging from —32°C in mid-November to —88°C in early August. With the return of direct solar radiation in spring, the stratosphere undergoes a four-month warming period (Fig. 11), a large portion of which is

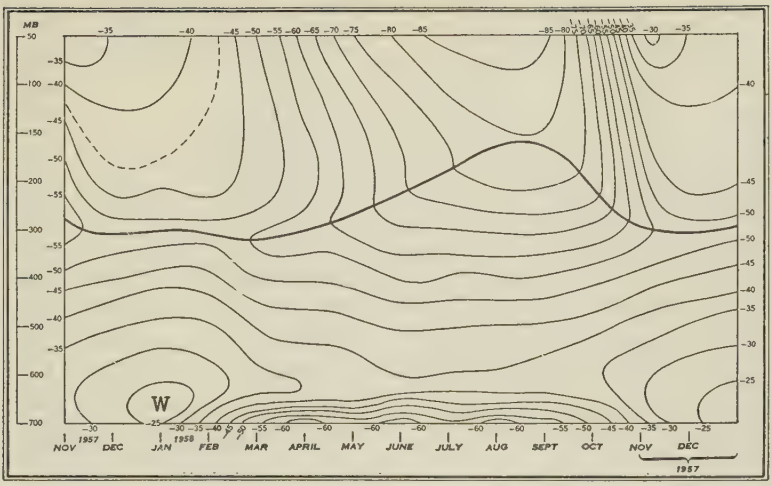


Fig. 11. *Variation of 30-Day Mean Temperature from the Surface (700-millibar level, on the South Polar Plateau) to an Altitude of 19 Kilometers (50 millibars) Over the IGY South Pole Station in late 1957 and Throughout 1958. Heavy line represents the mean tropopause.*

accomplished from mid-October to mid-November.

A surprising characteristic of the temperature regime of the south polar stratosphere is the abruptness with which it reverts from winter to summer temperature structure. This rapid transition was first pointed out by Harry Wexler of the Weather Bureau, who demonstrated it by the use of 10-day mean temperatures. He showed that, at the 50-millibar level over the South Pole Station in 1957, the temperature minimum was reached in mid-August and the maximum in late October and early November; this represents a total warming of 60°C (140°F) in less than three months, with 80% of it occurring during October. After early November, cooling begins at the 50-millibar level and continues through the summer solstice and into the winter night.

## Explosive Warming in 1958

Because of the extreme temperature change observed in October 1957, high priority was given to the collection of high-altitude temperature data for October 1958 over the South Pole Station. During the long winter night, when stratospheric temperatures fell below —90°C, very little temperature data were obtained above a height of 15 kilometers because of premature balloon bursts. However, with the return of direct solar radiation in the spring, and with the use of special high-flying balloons, burst altitudes increased to 30 kilometers, and on two occasions exceeded 37 kilometers.

Daily soundings from October 12 to 29, 1958, were used to construct a time-altitude section (Fig. 12) showing the daily temperatures at various heights during this period of rapid temperature change. It is apparent from this section that the rapid stratospheric warming is not a steady day-to-day process, but consists of a number of short-period temperature changes. On October 22, after a week of small temperature undulations, the explosive phase of the warming began; it strengthened on the 23rd and reached a maximum rate on the 24th, when a tremendous 12-hour rise of 19°C occurred at the 15-millibar level (27 kilometers). Little or no temperature change was observed on October 25th; on the 26th and 27th, the stratosphere began to cool, only to undergo renewed warming on the 28th.

Accompanying the rapid warming was a change in stratospheric circulation. At the South Pole Station, winds of over 60 meters per second were observed from directions between 120°E and 140°E following the period of intense warming, indicating the close proximity of a stratospheric jet stream.

To determine the propagation of temperature change with time for this particular warming, a time-altitude section was constructed to show the amount of change, in 24-hour periods, at various heights in the stratosphere (Fig. 13). A complex propagation of temperature change with time can be seen in the 8–34 kilometer region. The maximum rate of warming occurred first near a height of 10 kilometers and rose in height with time; it next occurred at the highest observed level (34 kilometers) where it was decreasing in height with time; and it last occurred at 25–27 kilometers.

A surprising feature apparent in this section is that many of the properties associated with warming are also noted in the cooling that followed:—i.e., the propagation of temperature decrease with time is similar to that of temperature increase, and the distribution of cooling maxima is similar to that of warming maxima. During this particular period, there appeared to be favored locations of temperature-change centers at heights of 9–10 kilometers and of 23–35 kilometers, with an absence of major change centers between 12 and 20 kilometers. As additional data become available, it will be of interest to determine whether this condition remains consistent through longer time periods.

## Geomagnetic and Ionospheric Disturbances at Time of 1958 Warming

On October 22, 1958, unusually intense sunspot activity was observed by theodolite from the South Pole Station. The relative sunspot number increased from 163 on the 21st to 214 on the 22nd. From October 14–21, the geomagnetic field, as observed at the South Pole Station had remained quiet and ionospheric absorption was normal, but at 0600 UT on the 22nd both became anomalous. A moderate geomagnetic disturbance lasting 9–10 hours was observed and ionosphere records indicated a rise in radio-wave absorption, followed one hour later by a sharp drop in F-2 critical frequency (the frequency above which radio waves completely penetrate the F-2 layer). At 1700 UT on the 22nd, very low critical frequencies, about 4½ megacycles per second, were observed in the F-2 region; critical frequencies did not rise above five megacycles on the 23rd, and did not reach the normal eight-megacycle level until 1700 UT on the 25th.

The onset of warming at the 10-millibar level was nearly concurrent with the beginning of the geomagnetic and ionospheric disturbances. On the other hand, the lowest daily total of sporadic-E clouds—clouds or patches of unusually high ionization in the

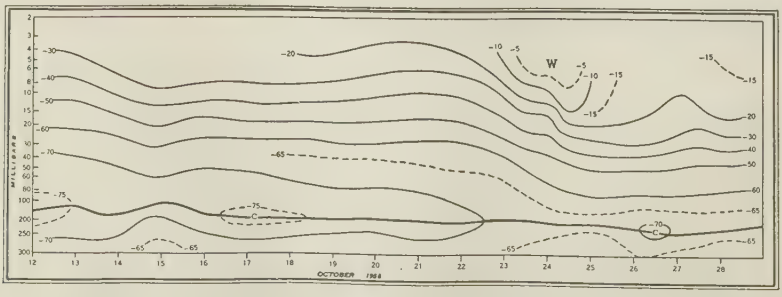


Fig. 12. *Time Section Showing Stratospheric Temperatures Over the IGY South Pole Station, October 12–29, 1958. Heavy line represents the mean tropopause.*

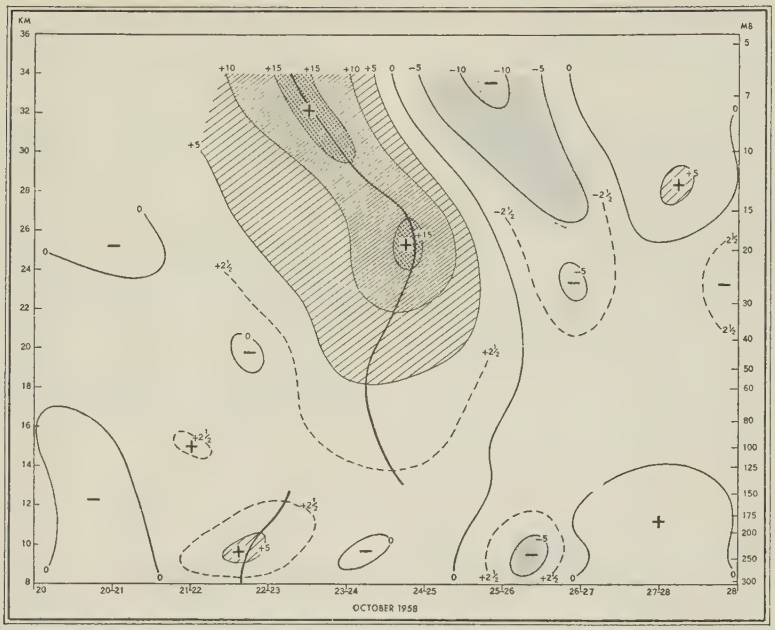


Fig. 13. *Time Section Showing Stratospheric 24-Hour Temperature Change Over the IGY South Pole Station, October 20–29, 1958.*

E-region (90–150 kilometers)—occurred on the 24th, the day that warming ended at the 10-millibar level.

## Warming Elsewhere Over Antarctica

It is interesting to note that warming of nearly equal magnitude to that over the South Pole region swept over a large portion of Antarctica within a 24-hour period beginning on October 22. There is a suggestion that the atmospheric region of maximum temperature change, which was first observed at Ellsworth Station, next moved over the South Pole and, although diminished in intensity, was last centered over the polar plateau.

Plots showing the time of occurrence of maximum temperature at 50 millibars over a number of Antarctic stations also suggest this pattern of temperature change. The US-IGY Amundsen-Scott South Pole Station, as well as the USSR-IGY Sovietskaya and Vostok Stations, all located high on the polar plateau, were the last to observe the maximum temperatures. Despite the long distances between stations and the sparseness of data for the intervening regions, the suggestion is strong that both maximum temperature and maximum temperature change last occurred over the high plateau of East Antarctica.

## Summary and Conclusions

Through the use of high-altitude sounding equipment and balloons, much was learned during the IGY about the south-polar stratospheric temperature structure in general, and about the extremely rapid spring warming in particular. It was observed that spring warming involves rapid daily temperature changes encompassing the stratosphere over most of Antarctica.

It is certain that circulation should be considered in attempts to explain the intimate relationship of temperature change to pressure change in these explosive warmings, and that these are associated in some

manner with absorption of solar ultraviolet radiation and corpuscular energy in the upper atmosphere.

Wexler has suggested a possible meteorological relation between disturbances in the lower atmosphere and in the ozonosphere (layer of ozone lying between heights of about 19 and 35 kilometers, depending upon season and latitude). He calls attention to the observed upward propagation of disturbances resulting from orographic lifting (upward motion of air over mountains), and suggests that major perturbations in the lower-atmospheric circulation could cause upward propagation of such disturbances to the level of the ozonosphere.

It was also noted that, during one particular spring period of rapid temperature rise, anomalies in the earth's magnetic field and in the ionosphere occurred nearly coincident with this rise. Whether the conjunction of stratospheric warming with magnetic and ionospheric disturbances was merely a coincidence or whether there was an actual physical connection may eventually be decided as additional data are accumulated.

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*This is the twenty-first of a series of bibliographic notes on IGY and IGC–1959 programs and findings. The references are selected largely from a bibliography under preparation in the Science and Technology Division of the Library of Congress. (An interim IGY bibliography, covering the period January 1951–August 1958, prepared by the Library and published by the Academy with support of the National Science Foundation, is available from the Academy, 2101 Constitution Avenue, N.W., Washington 25, D. C., for $1.00. The 64-page volume contains 704 references.)*


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